Research on the use of cylindrical cutting drums with blades in cascade for Miscanthus harvesting

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Abstract. In the current context of climate change, a special place is occupied by the field of energy plants. One of the renewable sources providing the biomass necessary for the generation of bioenergy, widely used in the last decades in the EU countries is the Miscanthus culture, which by capitalisation provides a series of economic benefits, but especially in terms of environment. This can be used for the production of electricity and/or thermal energy both in large power plants (30 MW +), which use thousands of tons of biomass annually, and in small domestic systems that use several tons, during the winter months. By using the Miscanthus in the combustion process, the carbon dioxide emissions are reduced and the methane emissions from the deposits are eliminated. In the case of applying the technology for Miscanthus culture direct harvesting (culture of perennial plants, over 2 m high, and high density), the technological process consists of cutting, chopping and loading in the means of transport of the harvested material. The paper presents the technological process of direct harvesting and analysis of the results obtained, achieved with the help of the trailed forage harvester CTF.

1 Introduction

In order to reduce the global warming due to the greenhouse gas emissions concentrated in the terrestrial atmosphere, a lower use of energy, especially the one derived from fossil fuels, is intended. The rapid reduction of energy resources derived from fossil fuels (coal, oil, natural gas) in parallel with the continuous increase of energy needs, requires increasing research efforts for the development of new sources of renewable energy [1].

Renewable energy is a natural renewable source, which can be produced, grown, regenerated at a comparable or faster rate than the rate of human consumption, derived from a wide range of resources such as: wind energy, solar energy, geothermal energy or biomass. Due to its variety, biomass is considered an energy source with a high degree of availability, and due to the cyclicality of the production and conversion processes it is considered a renewable source and with a positive impact on the environment. Biomass can also be produced by the special cultivation of plants for the generation of electricity, plants which are also called "energy plants". Energy plants can be grown on agricultural land that

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is not used in agriculture (usually land that is removed from the circuit for various reasons or land considered unfit for growing food plants). Compared to traditional agricultural plants, energy plants require less care and less mineral fertilizers and pesticides. One of the renewable sources providing the biomass necessary for the generation of bioenergy, widely used in the last decades in the EU countries is the Miscanthus culture [2], which by capitalization provides a series of economic benefits, but especially in terms of environment. For capitalising Miscanthus plants, they must be harvested. Miscanthus plants are harvested starting with the third year of vegetation, in February when the stalks reached an optimum humidity of 11 ... 12%.

Depending on the requirements of using the harvested material, there are two technological variants of harvesting [3, 4, 5], namely:

1. The technology of harvesting directly from the field with the forage harvester (trailed or self-propelled), which in the working process realizes the chopping and loading of the chopped mass in the means of transport, if the transport to the place of processing takes little time. The method, similar to that used for corn harvesting, is simpler and faster.

2. The divided harvesting technology, using the rotary mower for cutting and laying stalks in continuous furrow on the ground and baling them with balers in large-size parallelepipedic bales if long-term storage until processing or transport over long distances are intended. The method has the disadvantage that it is relatively slow and requires lower expenses.

In the case of applying the technology for Miscanthus culture (culture of perennial plants with a height of over 2 m, and high density) direct harvesting, the technological process consists of cutting, chopping and loading in the means of transport of the harvested material. The technological process is realized efficiently if the forage harvester is equipped with equipment for harvesting tall plants, that can realize the complete cutting of the plants (across the entire working width). Because the Miscanthus stalks, harvested with the combine, are used as fuel in the burners of the thermal power plants, without being subjected to further processing, it is recommended that the chopped matter size be 10 ... 15 mm.

Within the technological process of the combine, the most important working part is the chopping drum, which cuts the fodder according to dimensions required and throws them into the evacuation system in the combine due to peripheral speed and air current created by it.

The main objective of the experimental research was to verify the technological efficiency of the chopping drums with straight knives placed in a cascade in the process of harvesting the Miscanthus stems.

2 Theoretical research

The technological process of direct harvesting can also be carried out with the help of the trailed Miscanthus stalk harvester - CRM1.6, figure 1, assimilated at SC MECANICA CEAHLĂU SA Piatra Neamt for which INMA has designed and made the specialized equipment for harvesting Miscanthus stalks, called EPI.

**Fig. 1.** Trailed Miscanthus stalk harvester - CRM1.6

The harvester works in aggregate with 65-100 HP tractors. The actuation of the working parts is done from the tractor power take-off (PTO) through a cardanic transmission.

The trailed Miscanthus stalk harvester -CRM1.6- performs, during the working process, the cutting of Miscanthus plants in the field and directs them towards the harvester working parts which perform the chopping and loading of the chopped mass in a means of transport.

It works in aggregate with 65-125 HP wheeled tractors equipped with hydraulic lifters and has two chopping sections. The trailed Miscanthus stalk harvester - CRM1.6 - (fig. 1), is composed of a rolling frame on which is mounted Miscanthus harvesting equipment, cylindrical chopping drum with small straight blades cascading, outlet pipe, transmission for operating the working parts, a device for coupling the equipment to the harvester, hydraulic installation.

The equipment for harvesting Miscanthus consists of the following subassemblies: frame; transmission sections; assembled blade; right assembled rotor; left assembled rotor; left, right, plant deflector; left, right field separator; central splitter; main transmission. The equipment is provided with a system for coupling to the harvester, which is common with that of the other pieces of equipment and the controls for driving the working parts of the harvester with the working equipment (coupling and decoupling the movement of the working parts) are operated by the tractor driver, from the tractor cab, by coupling or decoupling the PTO.

Within the technological process of the harvester, the most important working part is the chopping drum, figure 2, [6, 7] which performs the fragmentation of the fodder to the required dimensions and throws it to the system for discharging from the harvester, due to the peripheral speed and the air flow created by it.
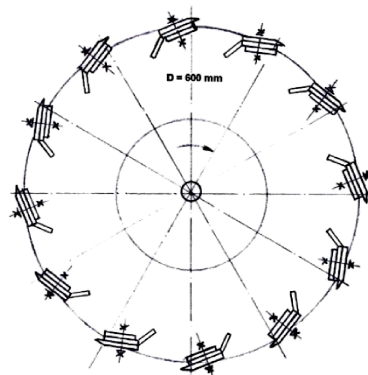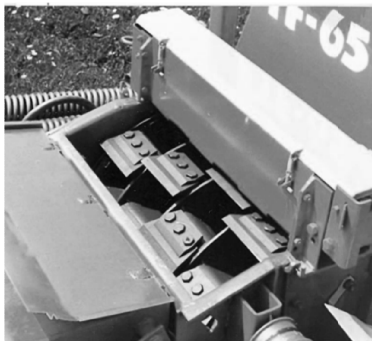
Fig. 2. Cylindrical chopping drum with small straight blades cascading

The power transmitted through the PTO, P_p, is calculated with the relation:

$$P_p = M_p \cdot \omega_{p.} \cdot 10^{-3} \ [\text{kW}] \qquad (1)$$

where:

- M_p is the torque measured from PTO shaft, in N·m;

- $\omega_p = \dfrac{\pi \cdot n_p}{30}$ - PTO shaft angular velocity rad/s;

- n_p – power take-off speed, in rpm.

The power required to tow the harvester on the horizontal field, P_t, is calculated with the relation:

$$P_t = F_t \cdot V_l \cdot 10^{-3} \qquad [kW] \qquad (2)$$

where:

- F_t is the traction force measured at the coupling bar in N.
- V_l - the working (travel) speed of the aggregate in m/s

The total power P_{tot}, for towing and operating the working parts of the harvester is given by the relation:

$$P_{tot} = P_p + P_t = \left(M_p \cdot \frac{\pi \cdot n}{30} + F_t \cdot V_l \right) \cdot 10^{-3} \quad [kW] \qquad (3)$$

3 Results and discussion

The trailed Miscanthus stalk harvester was tested in two locations: INMA Bucharest experimental lot cultivated with Miscanthus where the Harvester worked in aggregate with the NEW HOLLAND TD80D tractor (figure 3a) and in Copsa Mica (figure 3b) with 120 HP tractor.

a

b

Fig. 3. Aggregate tractor - trailed Miscanthus stalk harvester, during operation

The main technical characteristics of trailed combine for harvesting strains of Miscanthus - CRM1,6:

Trailed combination type; coupling on the lateral straps of the coupling mechanism
Power drive with , rpm   540
Type of cylindrical chopping drum with cascade knives
Chopping drum speed, rpm   890
Chopping length, mm   10… 25 (6 steps)
Diameter of chopping drum, mm   600
Number of knives on the drum, pcs   4x10
Material discharge height, m   3.5
Tractor for drive,   CP 65 ... 125
Miscanthus harvesting equipment
Constructive working width, m   1.6
Number of tooth rotors   2
Type of cutting machine,   with rotary disc
Effective working capacity at harvest, t / h   10
Productivity ha / hour   0.8

The working conditions and the indices realized in the test of the TRAILED MISCANTHUS STALK HARVESTER - CRM1.6 are presented in tables 1, 2 and 3.

Table 1. Working conditions

Den. No.	Specification	U M	Values
1	Harvested culture	-	Dry Miscanthus stalks
2	Plant mass production	t/ha	7.85
3	Vegetation year	-	two
4	Vegetation stage	-	Dry stalks
5	Field aspect	-	uniform without lying plants
6	Field height (average)	mm	1600 – 2800 (2000)
7	Average thickness of the plants at the cutting height	mm	8.80
8	Number of plants per m^2.	pc.	25
9	Humidity of plants when harvested	%	10.7

Table 2. Qualitative working indices

Den. No.	Specification	U M	Values			
			Test I	Test II	Test III	Average
1	Finger rotor speed	rpm	46	46.5	45.4	46
2	Blades speed	rpm	288.4	288.6	288.5	288.5
3	Working width	m	1.6	1.6	1.6	1.6
4	Plant cutting height	mm	120	130	145	120 – 145
5	Loss of material	%	≤ 5.2	≤ 5.5	≤ 5.3	≤ 5.3
6	The range of length Mscanthus	mm				
	0-15	%	22,7	24,9	23,5	23,7
	15,1-30	%	45,3	46,2	44,4	45,3
	30,1-50	%	12,3	8,6	12,2	11,0
	50,1-70	%	10,3	10,9	11,1	10,8
	70,1 -90	%	7,6	6,9	7,1	7,2
	90,1-100	%	1,2	1,9	1,1	1,4
	>100	%	0,6	0,6	0,6	0,6
	Total	%	100	100	100	100

Table 3. Operating indices

Den. No.	Size determined	U.M.	Values			
			Test I	**Test II**	**Test III**	**Average**
1	Working speed	km/h	5.8	6.1	6.3	6.1
2	Total power to drive the harvester in operation (without trailer coupled) (p_{tot})	kW	39.60	39.70	39.9	39.70
3	Effective working capacity (w_{ef}) (without towing the trailer)	t/h	7.6	7.9	8.1	7.9
4	Effective hourly working capacity	ha/h	0.75	0.77	0.81	0.8
5	Fuel consumption	l/ha	19.1	18.8	19.1	19
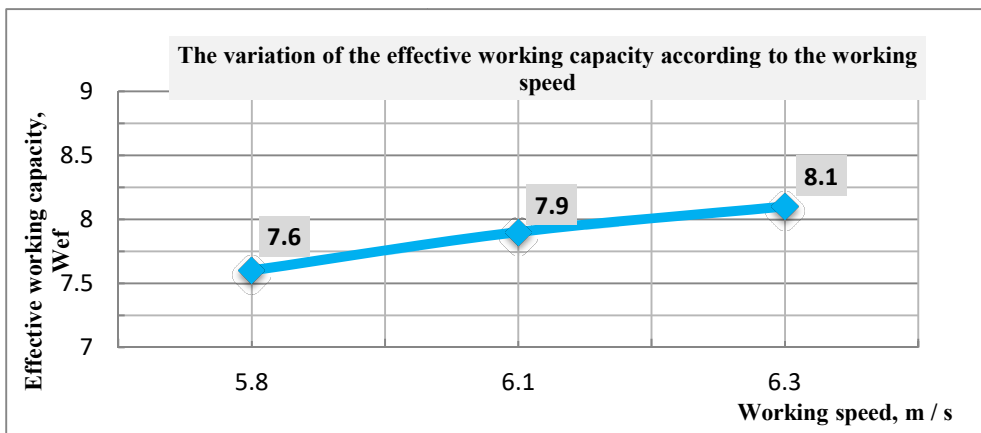
Fig. 4. Variation of operating indices according to the working speed
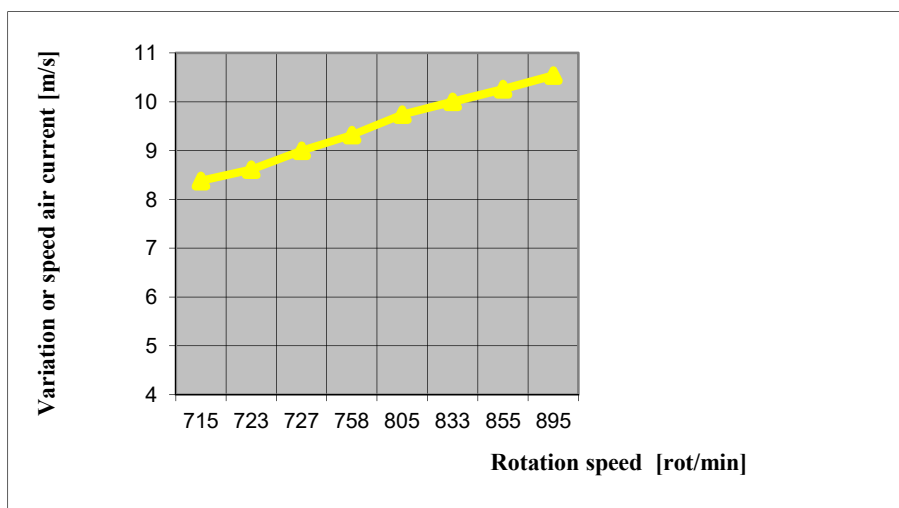
Fig. 5. Variation of speed of air current created by chopping drum depending on rotation speed

Analyzing the data in table no. 2, the following results were obtained:

-The effective working width was 1.6 m representing approx. 100% of the constructive working width;

-The cutting height was 120 - 145 mm (according to the adjustment made) and it was uniform across the entire working width.

-The chopping degree was determined for the chopped mass collected in the trailer.

The density of the chopped material, found in the collecting trailer was 78.65 kg/m3, the chopping degree of the chopped plants had values between 12 - 100 mm, and the particles with the length up to 50 mm represented approx. 80%, with a weight of 45% of the particles with the lengths between 15 - 30 mm.

Regarding the degree of chopping of plants, if we analyze the work [6] where the working process of the cylindrical chopping drum with small straight knives placed in cascade for harvesting corn for silo is studied: the chopping drum with cascade knives has the lowest power consumption, the chopping degree is comparable to the one for the Miscanthus culture with the difference that the effective working capacity is lower in the case of the Miscanthus.The effective working capacity is lower in the case of Miscanthus due to the different characteristics of the cultures approached. Also the distance of horizontal throwing of the chopped drum material with cascading knives (fig.2) is greater by approx. 1.5 m from the other drums analyzed in the paper [6]. During measurements, the Miscanthus harvester moved at a speed of 6.3 km/h.

The following conclusions regarding the operating indices were obtained from the analysis of the measurements:

- The actual torque at the tractor PTO required to operate the unloaded working bodies was determined for a tractor engine speed of 2200 rpm and a power take-off speed of 540 rpm resulting in a value of 7.85 daN m;
- During operation, the actual torque at the tractor PTO was determined under the same conditions having a value of 42.4 daN m;
- The traction force at the coupling bar of the tractor (F_t) was 210 daN if the trailer in which the harvested material was loaded moved parallel to the aggregate and 650 daN if the trailer was coupled in the back of the harvester and loaded with 600 kg;
- The pressure force of tow hitch on the tractor (F_{ap}) had a value of 310 daN in idling state and 315 daN loaded, resulting that the way of coupling the harvester to the tractor is appropriate and that the small variations that occur are due to the state of the land;
- The effective power at the PTO (P_p) was 5.98 kW idling and 28.4 kW loaded;
- The effective power for towing the harvester (P_p) was 3.9 kW if the trailer in which the harvested material was loaded moved parallel to the aggregate and 11.2 kW if the trailer was coupled in the back of the harvester;
- The total power for driving the operating harvester was determined without trailer coupled to the harvester (p_{tot}) having a value of 39.70 kW and achieving an effective working capacity (w_{ef}) of 7.9 t/h with a specific energy consumption for carrying out technological process (p_{tot}/w_{ef}) of 18 kW s/kg.

4 Conclusions

After the researches performed and results obtained, the following conclusions can be formulated:

- The cutting height was uniform and did not show large variations depending on the working speed of the tractor - trailed harvester aggregate;

- The values of the working capacity in exchange vary according to the working speed of the tractor aggregate. Thus for the average speed of 5.8 km/h the average hourly working

capacity has an average value of 7.6 t/h, and for the average speed of 6.3 km/h it has an average value of 7.9 t/h.

- The optimum working speed of the aggregate is 5.8 km/h and is imposed by the real field conditions. If the terrain is well levelled the working speed can reach 6.3 km/h.

- The trailed Miscanthus stalk harvester worked properly with the working parts clogging rarely, and the transport of the plants to the feeding and chopping system of the harvester was carried out continuously, without clogging.

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